



Advanced Stirling Converter Testing at GRC

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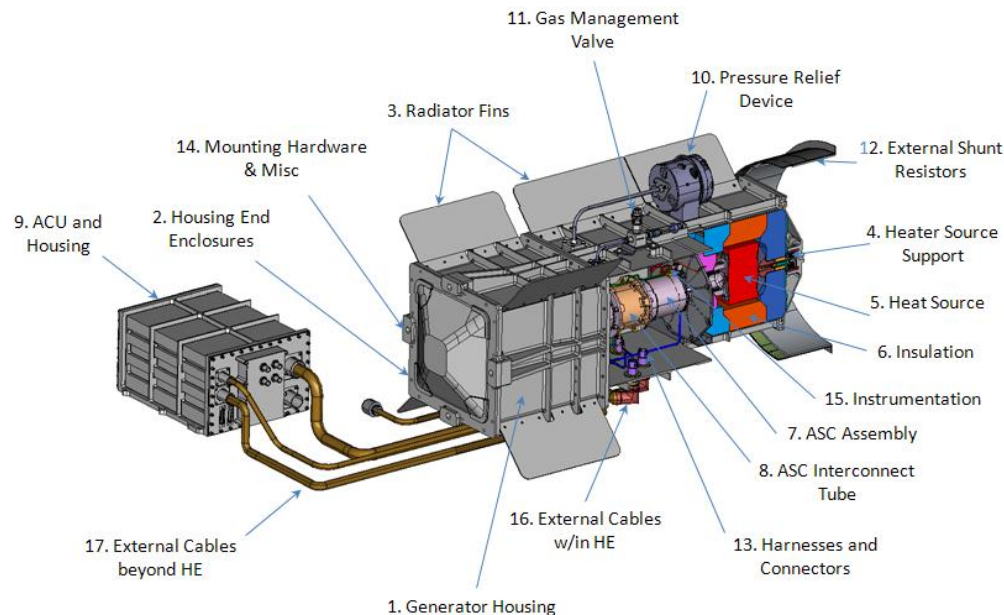
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Background



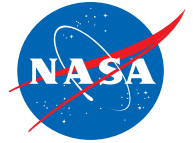
Advanced Stirling Radioisotope Generator

- Next generation radioisotope-fueled power system
- Lockheed Martin Space Systems is System Integration Contractor
- Suitable for deep-space or other missions without solar power
- Two dual-opposed free-piston Stirling convertors
- > 20% thermal-to-electric conversion at system level
- 1st use of dynamic energy conversion in space
- Necessitates demonstration of conversion technology long-term performance



ASRG System Schematic

Background



Advanced Stirling Convertor

- Designed and Manufactured by Sunpower, Inc.
- Development initiated in 2004 via NASA technology development contract
- 6 stages of development:
 1. ASC-0
 2. ASC-1
 3. ASC-1HS

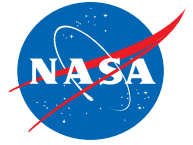
} Technology Development

 4. ASC-E - First Engineering Unit design
 5. ASC-E2 - Engineering Unit design with high-temp heater head
 6. ASC-E3 - Pathfinder for Flight Unit production



ASC-E3 as-built hardware

Test Methodology



Three types of tests are performed:

1. Performance Mapping

- Simulate range of expected operating temperatures
- Max/Min thermal input, max/min sink temperature

2. Durability Tests

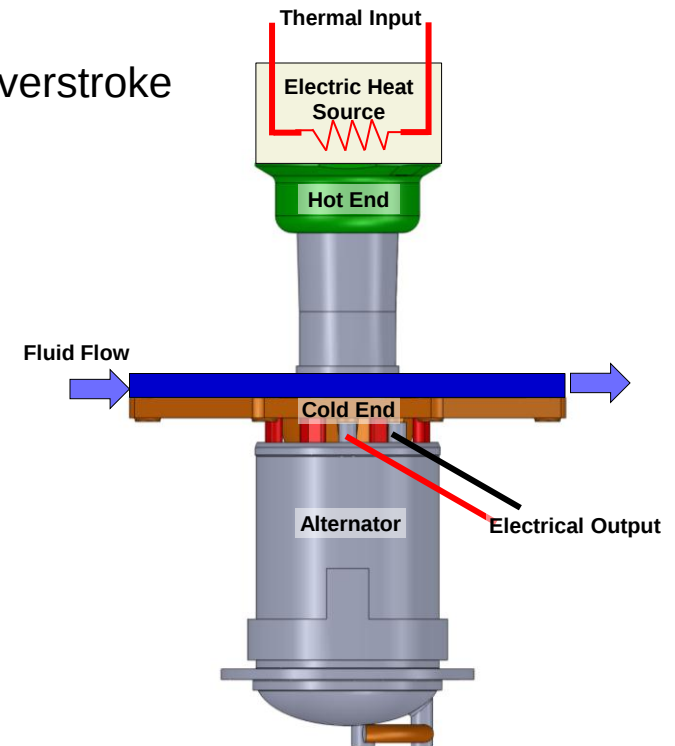
- Demonstrate and quantify margin of ASC design
- Start/stop cycling, static acceleration, launch vibration, overstroke

3. Extended Operation

- Goal : 10s of thousands of hours
- 24/7, unattended operation

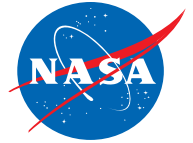
Implementation

- Electric heat source for heat input
- Laboratory circulator for heat rejection
- Automated data system
- Automated shutdown routines
- Thermocouples, thermistors for temperature
- Power meters for voltage, current, power
- LabView data acquisition software



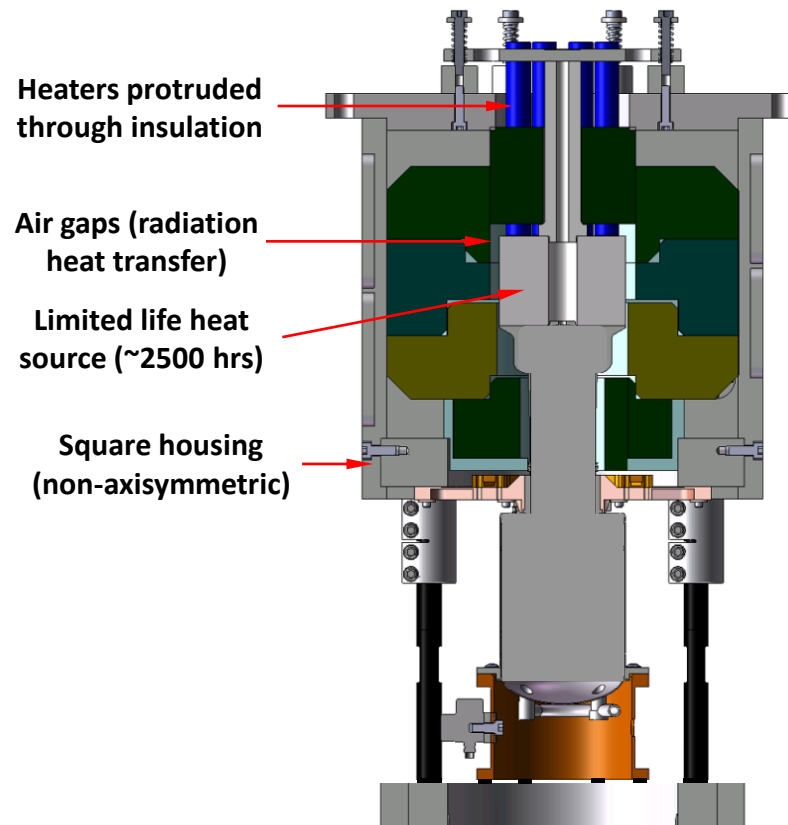
ASC Operation Schematic

Test Article Design



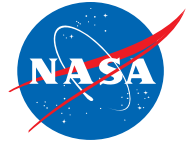
Previous test article designs needed improvement :

- Unify convertor test configuration between Sunpower and GRC locations
- Reduce thermal insulation losses
- Eliminate radiation heat transfer paths for more accurate finite element modeling
- Improve temperature measurements for more accurate modeling
- Improve electric heat source life



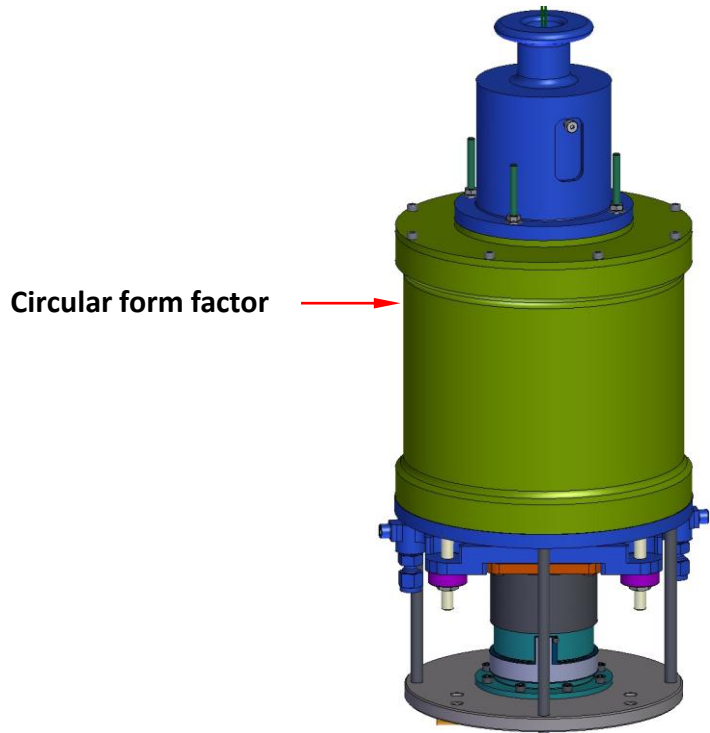
ASC-E2 Test Article Deficiencies

ASC-E3 Test Article

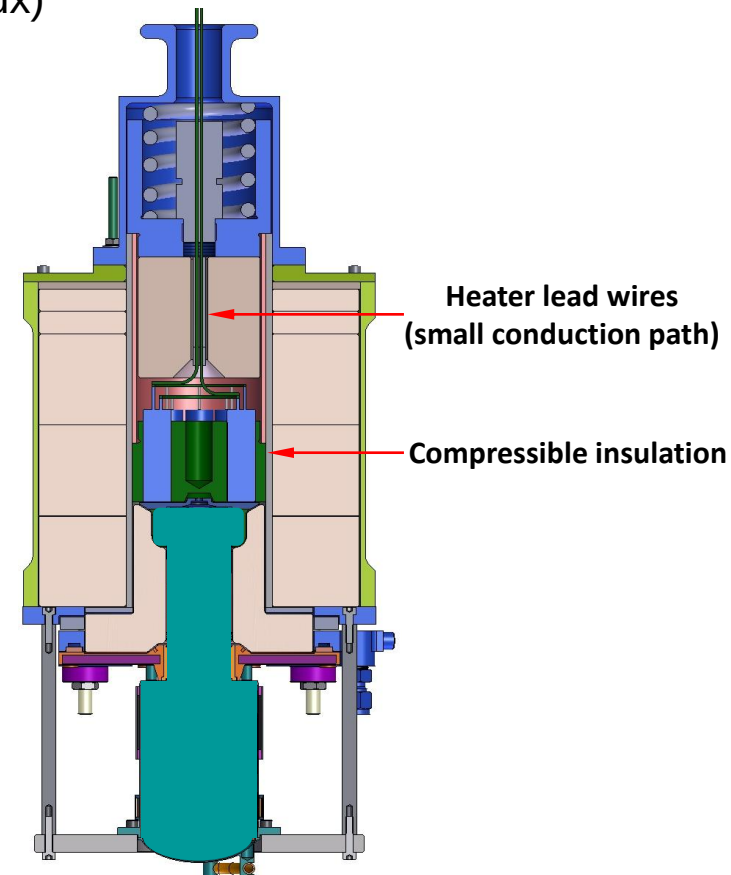


Improvements:

- Minimized heater lead losses
- Circular, axisymmetric insulation
- Air gaps filled with compressible insulation
- Longer life heat source (better cartridge fit, lower heat flux)
- Additional temp measurements throughout



ASC-E3 Test Article External View

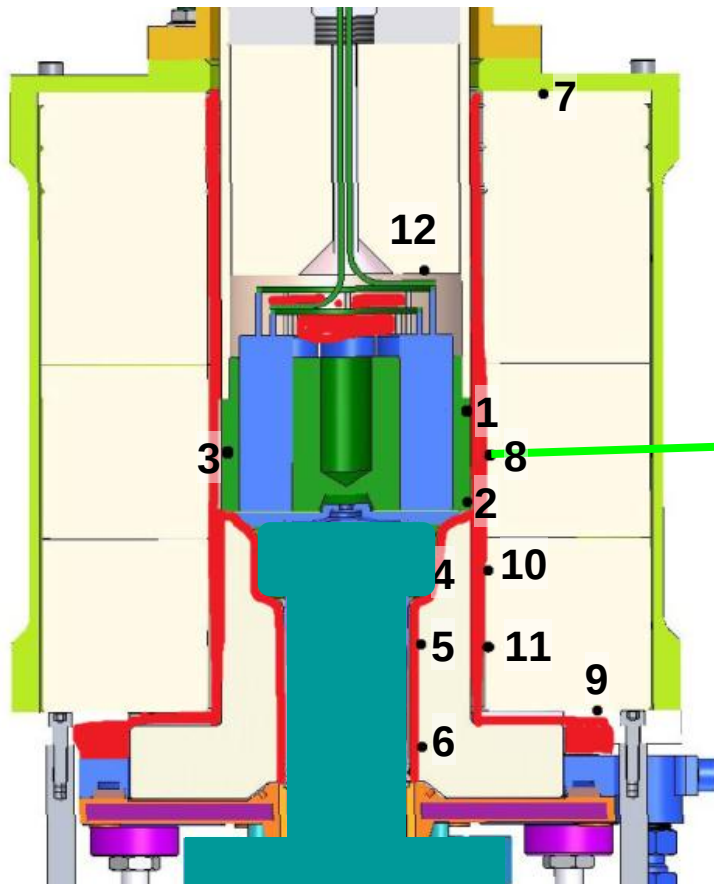


ASC-E3 Test Article Internal View

ASC-E3 Temperature Measurements

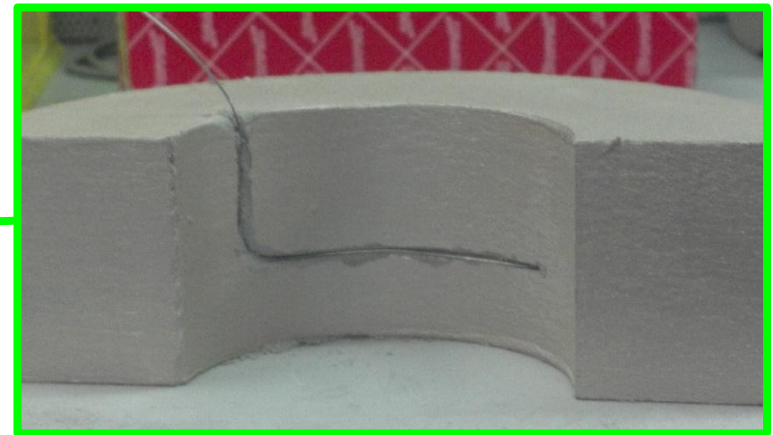


- Auxiliary thermocouples are required for thermal model
- Embedded in insulation before assembly – more accurate placement
- Aligned with isotherms to reduce disturbance of object temperature



Gap-Filling Insulation

Thermocouple Locations



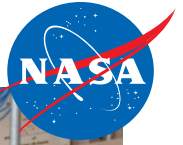
Example auxiliary thermocouple installed in microporous insulation piece

Placed along an isotherm to reduce local temperature disturbance



ASC-E3 Test Station

- Simultaneous operation of a pair of convertors
- Vertical orientation
- Independent operating condition control



Test Rack
Data acquisition
Monitoring
Operating point control

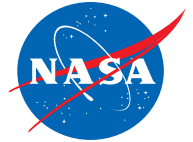
2 Convertors
Side-by-side
Vertical orientation

Circulators
Cold-end temp control

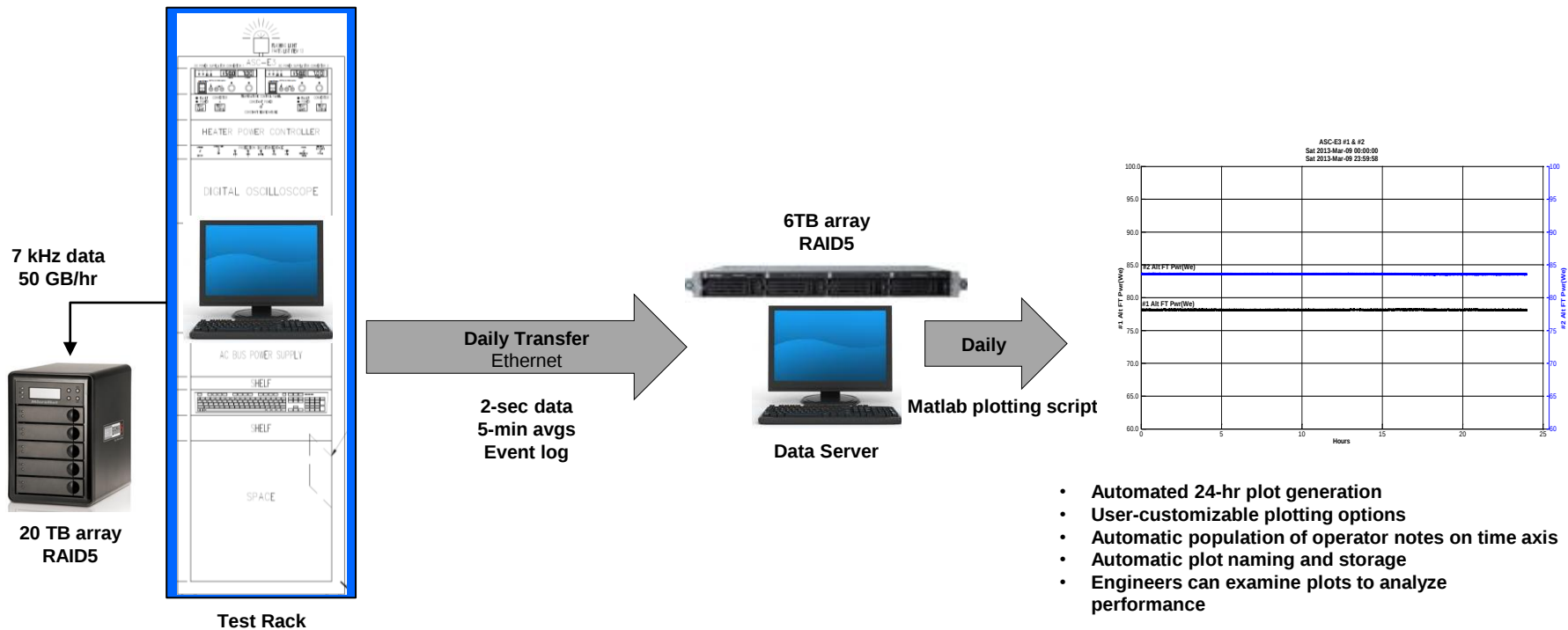


ASC-E3 Test Station

ASC-E3 Data Archival and Processing



- Centralized storage of data from all test stations
- All parameters measured and recorded every 2 seconds
- 5-minute-window average point stored each hour
- Dynamic data sampled and stored at 7 kHz
- Operator notes stored in an event log

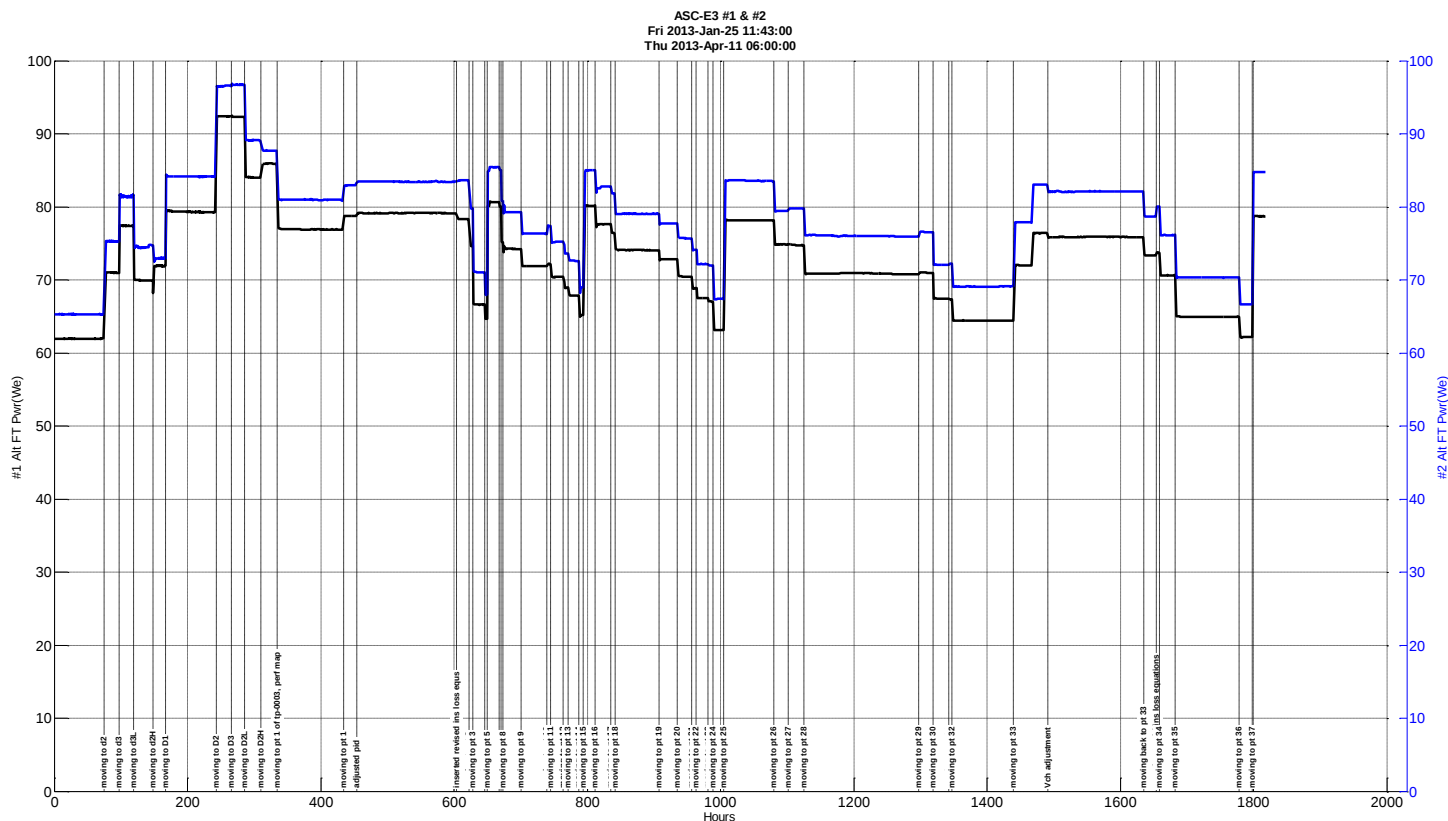


ASC-E3 Operational Data



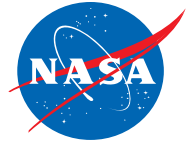
ASC-E3 #1 & #2 runtime each > 2,000 hrs

- No instabilities observed over a range of operating conditions
- No signs of heat source failure
- Daily 2-second data plots show steady operation



Plot of hourly 5-minute averages over 1,800 hours
Various operating conditions

ASC Operation Summary



ASC Model	# Units	Total Runtime	Status
ASC-0	4	92,000	Ongoing
ASC-1	2	3,700	Ongoing
ASC-1HS	2	11,000	Complete
ASC-E	4	100,000	Ongoing
ASC-E2	8	54,000	Ongoing
ASC-E3	2	4,000	Ongoing

Total = 263,900